

respect to that of the associated adakites can be explained by melting of a sub-arc mantle that had been variably enriched by recycling of continental material into the sub-arc mantle. Collectively, the Nd and Hf isotopic characteristics of the MA can be attributed to the decoupling of these elements during recycling of continental material into the sub-arc mantle prior to 2.7 Ga arc. During this recycling process, Hf was more conservative than Nd, suggesting sub-arc mantle enrichment by fluids [2-3]. Since the late Archean Wawa adakites and magnesian andesites were generated by subduction zone processes similar to those operating in Cenozoic arcs, it is likely that late Archean oceanic crust, and island arc crust, was also created and destroyed by geodynamic processes similar to modern plate tectonics. In the Late Archean, crustal recycling and slab melting therefore played an important role for the generation of heterogeneity in the Archean upper mantle.

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V61D-11 1120h

Lithium and Boron Isotopes in the Aleutian Islands: Contribution of Marine Sediments to Island Arc Magmas

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The Aleutian Arc is characterized by the presence of thick terrigenous sediments in the trench and fracture zones on the down-going plate, and therefore provides a unique setting for assessing the role of sediments with respect to other components in arc magma genesis.

We have measured Li and B isotope compositions of the sediments from DSDP site 183 near the northern edge of the Aleutian abyssal plain and basalts from several Aleutian islands. The upper 200 m of the sediment core consist of ash-rich diatomaceous ooze and have $\delta^7\text{Li} = 4.8$ to 5.6‰ and $\delta^{11}\text{B} = 2.9$ to 5.3‰ . The underlying clay and silty turbidites are Li rich, and have $\delta^7\text{Li} = 1.3$ to 2.4‰ and $\delta^{11}\text{B} = -3$ to 1.2‰ . Thus the sediments subducted beneath the Aleutian Arc have Li isotope compositions that are MORB-like or lighter, whereas oceanic crust altered by seawater at low temperature may be isotopically heavier than fresh MORB.

Basalts from Segum Island are especially enriched in Li and B with elevated Li/Y (to 0.84) and B/Nb (to 33). $\delta^7\text{Li}$ values of Segum basalts vary between 2.0 and 4.3‰ and $\delta^{11}\text{B}$ values are between 1.9 and 3.5‰. These isotopic data suggest that sediments may comprise a significant source of enrichment of fluid mobile elements at Segum due to the focusing effect of Amlia Fracture Zone. Recheshnoi is also highly enriched in Li (Li/Y to 1.1), with $\delta^7\text{Li} = 1.0$ to 3.5‰ . In contrast, Kanaga samples show low Li/Y and B/Nb values and slightly higher $\delta^7\text{Li}$ (3.8 to 5.8‰) and lower $\delta^{11}\text{B}$ (-0.25 to 1.6‰). Other islands (Yunaska, Okmok, and Shishaldin) show a similar range of $\delta^7\text{Li}$ values (2 to 4‰).

The restricted range and relatively light $\delta^7\text{Li}$ observed in this study are consistent with previous results from other Aleutian islands and other arcs (Tomascak et al., 2002). This has been attributed to retention of the slab-derived Li in the subarc mantle. Our data from the Aleutians suggest that another explanation for the MORB-like $\delta^7\text{Li}$ values of arc lavas may be the dominance of input from the sediments.

V61D-12 1135h

Lithium Content and Isotopic Composition of the Upper Continental Crust

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The lithium isotopic composition of the upper continental crust is characterized through measurements of Li abundance and isotopic composition in a suite of sedimentary rocks [13 loess from USA, Europe, New Zealand and China (Taylor et al., 1982), 9 Post-Achaean Australian shales (Taylor & McLennan, 1985)] and a variety of granites [2 S-type granites and 8 I-type granites from Australia (Chappell, 1984); and 5 granite composites from China (Gao et al., 1998)]. These lithologies give similar and light lithium isotopic values relative to the mantle ($\delta^7\text{Li} = -3$ to $+5\text{‰}$ for loess (average: $+0.3$); -3 to $+3\text{‰}$ for shales (average: -0.8) and -3 to $+3\text{‰}$ for all granites (average: -0.2). We estimate the lithium isotopic composition of the upper continental crust is light, around $0 \pm 2\text{‰}$. From the Li content of loess (30 ± 10 ppm) and a correlation between Li content and Al_2O_3 in shales, we estimate the upper crustal Li abundance at 40 ± 10 ppm.

The shale data also yield insights into the mechanism of lithium isotope fractionation during water-sediment interaction. There is a positive correlation between $\delta^7\text{Li}$, Li content and the chemical index of alteration (CIA), suggesting that as shales or their source regions become more weathered, more ^7Li is taken up from water (analogous to the uptake of seawater Li by hydrothermally altered MORB, as detailed by Chan et al., 1992).

V61D-13 1150h

Lithium isotopic composition of xenolithic eclogites: implications for subduction zone processes

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Lithium isotopes are strongly fractionated at the Earth's surface. Seawater Li is very heavy ($\delta^7\text{Li} = +32\text{‰}$) compared to that in mantle-derived magmas (MORB = $+2$ to $+6\text{‰}$). Because heavy seawater Li is incorporated into altered oceanic crust (Chan et al., 1992, EPSL), Li isotopes may provide a new tool for tracing recycled oceanic crust in the Earth's mantle. However, Li systematics of island arc basalts are not straightforward. In most arc lavas no correlations exist between $\delta^7\text{Li}$ and other indicators of subduction (e.g., $\delta^{11}\text{B}$) and most arc lavas $\delta^7\text{Li}$ values overlap with those of MORB (Tomascak et al., 2002, EPSL). What happens to the heavy Li that is subducted? Recent investigation of Alpine eclogites, which are analogs of subducted, hydrothermally altered oceanic crust (Zack et al., EPSL, submitted), show them to have light $\delta^7\text{Li}$, ranging from 11 to $+3\text{‰}$. This is significantly lighter than fresh or altered MORB, suggesting that Li is fractionated during dehydration of the slab, with heavy seawater Li being lost early in the subduction process, perhaps to the forearc mantle. We have measured the $\delta^7\text{Li}$ of clean omphacites separated from xenolithic eclogites from the Mesozoic Koidu kimberlites, Sierra Leone. Previous studies have shown that the low MgO suite of eclogites from Koidu has geochemical properties of hydrothermally altered Archean oceanic crust (Barth et al., 2001, GCA; 2003, Prec. Res., in press). Omphacites from these eclogites have $\delta^7\text{Li}$ ranging from 2 to $+5\text{‰}$. Eclogites with $\delta^{18}\text{O}$ heavier than normal mantle range are the only samples to show $\delta^7\text{Li}$ that deviates from the MORB range (to lighter values), whereas eclogites with $\delta^{18}\text{O}$ lighter than normal mantle have $\delta^7\text{Li}$ that falls within the MORB range. We interpret the eclogites with heavy $\delta^{18}\text{O}$ and light Li to represent former oceanic crust that was hydrothermally altered at low temperatures, which increased both $\delta^{18}\text{O}$ and $\delta^7\text{Li}$. Like the Alpine eclogites, this crust lost much of its heavy Li in the earliest dehydration reactions accompanying subduction, leaving light Li behind. In contrast, eclogites with

$\delta^{18}\text{O}$ lighter than the normal mantle range have Li isotopes that are indistinguishable from MORB. This is consistent with high temperature sea floor alteration having limited impact on $\delta^7\text{Li}$, as recently shown by Chan et al. (2002, EPSL).

V62A MCC: Hall C Saturday 1330h

Evolution of the Igneous Rocks 2002 Edition IV Posters (joint with OS, P)

Presiding: Y Zhang, University of Michigan; J R Allwardt, Stanford University

V62A-1375 1330h POSTER

An Empirical Model for the Calorimetrically-Defined Glass Transition Temperature with Applications to Natural Systems

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Glassy rocks have long held a special fascination for petrologists and geochemists because they record the composition of the melt phase attending magmatic processes. Naturally-occurring silicate glasses form under a variety of geological conditions and they commonly form the main constituent in silicic volcanic rocks and in rapidly cooled mafic rocks. Glass also occurs in rocks with cooling histories that are substantially slower, such as the interiors of lava flows or mantle xenoliths. The glass transition temperature (T_g) marks the transition from the liquid to the glassy state. From a petrological perspective, the calorimetrically-defined glass transition temperature is an important limiting value for the temperature conditions at which many magmatic processes take place. Glass formation is a boundary between changing environmental states. Above T_g , rates of nucleation, crystallization and vesiculation are sufficiently fast to drive magmatic processes. Conversely, where the liquid line of descent (e.g., T-X *Melt* path) intersects the T_g of the melt, glass forms and many magmatic processes effectively cease.

The purpose of this paper is to provide a means of exploring the T-X *Melt* conditions for glass formation in natural magmatic systems. Specifically, we present an empirical model of predicting the thermodynamic glass transition temperature (T_g) as a function of melt composition. Operationally, the model produces temperature-dependent expressions for the heat contents of a silicate melt and glass of known composition. The point of intersection of the heat content curves for glass and melt defines the calorimetric value of T_g . Our model is constructed from experimental calorimetric heat content and differential scanning calorimetric (DSC) heat capacity measurements on silicate melts and glasses produced over the past 20 years. Calorimetric data in the model include over 500 experiments on 60 melt compositions and 250 observations on 30 glass compositions. Additional constraints on the model derive from independent estimates of the thermodynamic T_g . The model reproduces most of the measured calorimetric-values of T_g to within 30°C . The model also provides volcanologists with a tool for tracking ($T_{Magma} - T_g$) through magmatic processes such as fractional crystallization, vesiculation, partial melting. It can be used to forecast the termination of liquid lines of descent by glass formation and provides geothermometric constraints on magmatic systems by converting glass compositions into minimum pre-eruption temperatures.

V62A-1376 1330h POSTER

Viscosity of Hydrous Rhyolitic Melts

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It is critical to understand and to be able to predict viscosity of hydrous silicate melts for understanding

magma transport, bubble growth, volcanic eruptions, and magma fragmentation. We report new viscosity data for hydrous rhyolitic melt in the viscosity range of 10^9 to 10^{15} Pa s based on the kinetics of hydrous species reaction in the melt upon cooling (i.e., based on the equivalence between the glass transition temperature and the apparent equilibrium temperature). We also report viscosity data obtained from bubble growth experiments. Our data show that the viscosity model of Hess and Dingwell (1996) systematically overestimates the viscosity of hydrous rhyolitic melt at the high viscosity range by a factor of 2 to 4 (still within their stated 2σ uncertainty). Another problem with the model of Hess and Dingwell is that the functional dependence of viscosity on total H_2O content cannot be extended to dry melt, as total H_2O content decreases to zero, the viscosity would first increase, and then decrease to zero. A zero viscosity for a dry melt makes no sense. Hence we need a mixing law for hydrous melt viscosity that is extendible to dry melts. By examining the viscosity of rhyolitic melts containing 6 ppm to about 8.0 wt% total H_2O (both our own data and literature data), we propose the following relation for the dependence of viscosity on total H_2O content:

$$1/\eta = 1/\eta_1 + (1/\eta_2 - 1/\eta_1)x^n \approx 1/\eta_1 + x^n/\eta_2$$

where η is viscosity and $1/\eta$ is fluidity, η_1 is the viscosity of the dry melt, x is the mole fraction of total dissolved H_2O , n and η_2 are two fitting parameters, and η_2 can be identified to be the viscosity of the hypothetical melt consisting of pure H_2O (η_2 cannot be directly measured since such a melt does not exist). The above equation appears to work well for the viscosity of hydrous rhyolitic melts. By fitting hydrous rhyolitic melt viscosity with the above equation, we find that rhyolitic melt viscosity vary by 1.2 orders of magnitude from 0.1 wt% total H_2O to a dry melt (with less than 100 ppm total H_2O). The effect of H_2O on viscosity depends on temperature.

Some authors often report viscosity of dry melts without reporting the H_2O concentration. Because such a melt may still contain some H_2O , such as several hundred ppm, it is possible that the minute H_2O content still affects the melt viscosity significantly, especially at low temperatures (i.e., high viscosity). Some inconsistency in literature viscosity data (such as viscosity of anorthite melt) might be attributed to small variations in H_2O content in the sample. Hence it is critical for experimentalists to report total H_2O content even for nominally dry melt.

We are developing a general model to predict the viscosity of hydrous rhyolitic melts as a function of temperature and H_2O content.

V62A-1377 1330h POSTER

Structural Environments of Chloride in Silicate and Aluminosilicate Glasses: CI-35 NMR of a Volatile Species

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As a volatile species, chloride behavior affects the nature and timing of magmatic degassing. Chloride is also recognized as an important complexing agent for metals in hydrothermal ore fluids and is directly related to many mineral deposits. In silicate melts, chloride solubilities have been observed to be strongly dependent on melt composition, and from these studies chlorine speciation has been inferred. However, little direct spectroscopic data is available to constrain the chemical and structural environments of chlorine in these systems. As such, the local environments of chlorine anions in several silicate and aluminosilicate glasses were probed using chlorine-35 MAS NMR. NMR spectra were obtained at 14.1 and 18.8 T fields for a series of Na- and Ca-silicate and aluminosilicate glasses with 1 wt % Cl. Peaks are roughly Gaussian in shape, much narrower than the total chemical shift range for the nuclei, and contributions to peak widths are primarily from quadrupole interactions (W_q) and to a lesser extent chemical shift distribution (W_{csd}). Peak widths (FWHM), W_q , and W_{csd} at 14.1 T, isotropic chemical shifts (relative to 1 M aq. NaCl), and mean quadrupole coupling constants ($\eta = 7$) for the samples probed are: Na-silicate (6210 ± 80 Hz, 92 ± 3 ppm, 50 ± 2 ppm, -70 ± 5 ppm, 3.3 ± 1 Hz), Ca-silicate (11750 ± 70 Hz, 186 ± 4 ppm, 72 ± 5 ppm, -50 ± 15 ppm, 3.2 ± 4 Hz), Ca-silicate (11250 ± 590 Hz, 175 ± 16 ppm, 78 ± 6 ppm, 81 ± 20 ppm, 4.4 ± 4 Hz), and Ca-aluminosilicate (12900 ± 240 Hz, 217 ± 6 ppm, 33 ± 10 ppm, 14 ± 39 ppm, 3.5 ± 9 Hz). Modeling of the mixed cation (Ca-Na) silicate glass suggests that most (>60%) Cl in the sample is in a mixed bonding environment with a significant amount (~25%) completely Na-coordinated and a minor amount (< 10%) completely Ca-coordinated. There is no evidence for significant Cl-Al bonding and quantization of peak intensities suggests that there is little to no "NMR-invisible" Cl in the samples due to peak broadening caused by a large quadrupole coupling constant. This observation

is mirrored in the relative instability of Cl-Al bonds in crystalline solids.

V62A-1378 1330h POSTER

Ca-Mg mixing on the enstatite-wollastonite (En-Wo) join: an investigation using Oxygen-17 MAS and 3QMAS NMR of silicate glasses

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The abundance of pyroxenes in the crust and upper mantle has made the enstatite-diopside-wollastonite (En-Di-Wo) join one of the most studied systems in mineralogy and petrology. In addition, based on the non-bridging oxygen to tetrahedron ratio (NBO/T) and the high percentage of Mg, the En-rich portion of the En-Di join could be used as a zeroth approximation for the composition of primitive mantle melts. As more elements are added to this system, a more accurate picture of the structure of mantle based melts may be obtained. Despite the geologic importance of this composition and the abundance of pyroxenes, relatively little work has been done on the structure of Ca-Mg silicate glasses and melts.

Previous studies have determined that the viscosity and configurational entropy data for glasses along the En-Wo join are consistent with ideal mixing of the modifier cations (Neuville and Richet, 1991). Oxygen-17 (¹⁷O) magic-angle spinning (MAS) NMR has also been used to investigate mixing in the glasses of this system, but severe overlap of the peak locations for the Mg-NBO and the Si-O-Si bonds have hindered a quantitative approach (Kirkpatrick, 1986). However, a recent study of crystalline pyroxenes found that the Mg-NBO and Si-O-Si peaks are well resolved in the isotropic dimension of the two-dimensional, triple-quantum MAS (3QMAS) spectra (Ashbrook et al., 2002). This finding allows ¹⁷O 3QMAS to directly investigate the Ca and Mg-NBO mixing in silicate glasses. As shown in the 3QMAS spectra of the endmember glasses of this study, there is significant separation in both dimensions between the Ca-NBO (-62 and 97 ppm in isotropic and MAS dimensions, respectively) and Mg-NBO (-32 and 35 ppm) peaks. The NBO signal of the diopside glass spectrum looks as though it is one broad peak centered at -45 and 66 ppm, which encompasses the entire range of chemical shifts from the Ca-NBO to Mg-NBO environments. Therefore, the diopside glass contains varied NBO environments ranging from that of wollastonite-like to enstatite-like glasses and everything in between. This suggests that this is a highly disordered system, which is consistent with the thermodynamic and viscosity data.

V62A-1379 1330h POSTER

Heats of mixing of silicate liquid in the systems Diopside-Anorthite-Akermanite, Diopside-Anorthite-Forsterite and Diopside-Silica

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Fusion enthalpies were measured by differential scanning calorimetry (DSC) using Setaram MHTC calorimeter for the mineral mixtures of eutectic compositions in the systems anorthite-diopside (An42Di58, wt% ratio), anorthite-akermanite (An46Ak54), akermanite-diopside (Ak42Di58), diopside-silica (Di84Qt16), and anorthite-diopside-forsterite (Di49Fo7.5An43), along with akermanite. Fusion enthalpies for the Di49Fo7.5An43.5 and akermanite were 113.5+-3.9 and 128.9+-2.4 kJ/mol, respectively. Those value agrees with that determined by drop calorimetry in previous studies. Heats of mixing of silicate liquid in those systems were calculated based on the DSC data and thermodynamic data of pure end-members. The liquids of Di49Fo7.5An43.5, An42Di58, An46Ak54, and Ak42Di58 have negative excess enthalpies of 0 -5 kJ/mol, whereas the Di84Qt16 liquid has positive excess enthalpy of about 5 kJ/mol. Those values are consistent with excess enthalpies estimated by thermodynamic analyses of phase equilibria of the above systems. The measured excess enthalpies investigated in this study are of smaller magnitude than the error in typical transposed-temperature drop calorimetry (+-10-15 kJ/mol). However, the small excess enthalpies cannot be ignored in petrological

applications based on thermodynamic calculation, because differences of enthalpy by +10 -10 kJ/mol affect phase equilibria considerably, resulting in differences of 50-150 K for saturation temperatures of minerals. We concluded that the differential scanning calorimetry is useful technique for direct calorimetric measurement of small endothermic or exothermic heat of mixing in silicate liquid with sufficient precision.

V62A-1380 1330h POSTER

Large-scale evolutionary geochemical and isotopic patterns: How do igneous rocks at convergent margins evolve ?

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Convergent continental margins are the main site of crustal growth. Changing geochemical and isotopic characteristics of igneous arc rocks can monitor their large-scale compositional evolution. We present examples from three Andean suites of arc rocks with systematically changing trace element, and Sr and Nd isotopic characteristics over time. (1) In southern Chile (40°-53°S), the evolution of the north Patagonian batholith (150 Ma to Present) shows two main stages. ⁸⁷Sr/⁸⁶Sr ratios first decrease from higher, crust-like to lower, island arc-like characteristics from 150-40 Ma, before they increase again to higher, crust-like ratios from 40 Ma to Present. Nd isotopes show a contemporaneous increase from low to higher ¹⁴³Nd/¹⁴⁴Nd ratios, before they drop again to lower ratios. (2) In central Chile (31°-34°S), the evolution of the coastal batholith (330-80 Ma) shows low and largely constant, island-arc like La/Yb ratios. ⁸⁷Sr/⁸⁶Sr ratios gradually decrease, from higher, crust-like to lower, island arc-like ratios, and ¹⁴³Nd/¹⁴⁴Nd ratios gradually increase. (3) In northern Chile (21°-26°S), a step-wise eastward-migrating main-arc axis from 200 Ma to present produced a collage of four, largely parallel, eastward-younging arc systems, each separated by a 5-10 m.y. magmatic gap of 50-100 km. Igneous rocks from the north Chilean arcs show evolutionary La/Yb ratios, and Sr and Nd isotopic characteristics. La/Yb ratios show a repeated increase in La/Yb ratios and ⁸⁷Sr/⁸⁶Sr ratios, and decrease in ¹⁴³Nd/¹⁴⁴Nd ratios within each arc system. Each individual arc system reflects crustal thickening over time, from an immature Jurassic island arc to the mature, orogenic continental arc of the central Andean Western Cordillera.

Detailed studies show that the geochemical and isotopic characteristics at individual volcanic centers may be more complex, yet on a larger scale the geochemical and isotopic signatures follow distinct evolutionary patterns. The existence of such patterns may be controlled by geodynamic changes of the subducting slab (e.g. convergence rate, subduction angle, plateau subduction), but the changing geochemical and isotopic signatures imposed on the melt are due to interaction with changing thickness (and age and composition) of the overlying crust. As the recent thick, orogenic Andean crust is mainly a product of crustal shortening, the evolutionary patterns provide a sensitive tool for monitoring the different stages of the Andean Orogeny.

V62A-1381 1330h POSTER

Plagioclase-Liquid Trace Element Oxygen Barometry

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Bowens early work on the plagioclase system recognized the importance of this mineral as a persistent phase along the liquid line of descent of magmas over a range of composition from mafic to felsic. Textures and compositional zoning in this mineral have since been exploited extensively by experiment and applied to many igneous rocks series. We have studied the partitioning of trace elements between plagioclase and liquid with a view to using its trace element signature as an oxygen barometer. Experiments were performed between 1100 and 1200 C on two natural basalts and select compositions in the Di-Ab-An system at 100 kPa over a range of fO₂ from 0 to 3.5 log units below the nickel-bunsenite (NNO) oxygen buffer. Run products were analyzed using LAICPMS. Equilibrium was tested by reversed and time series experiments. The results show an order of magnitude change in partition coefficients (D) for incompatible polyvalent cations (V, Mn) between NNO-3.5 and NNO-1, likely reflecting the preference of plagioclase structure to partition certain valence states of these two elements. The partition of other highly incompatible monovalent trace elements (Nb, Zr, Y) also show a change with fO₂, whereas

more compatible elements (Ba, Sr, Ga) show little or no change. This is partly attributed to charge coupled substitutions for the high valence cations, changes in the redox state of Fe, or crystal chemical effects. Application of the D for Mn and V to a mid-Atlantic MORB and Mt. Adams basaltic andesite produced empirical FO2 estimates consistent with other estimates. More data are needed to understand the role of crystal composition and T in order to extend this method to more Si-rich magmas. With the proliferation of trace element microanalysis in igneous rocks and minerals, this O barometer may serve as a simple and effective method to examine the open or closed system behavior of O along the liquid line of descent of magmas from basalt to dacite in composition.

V62A-1382 1330h POSTER

Trace Element Evolution of Quartz During Igneous Differentiation of Granitic Melts: is it Erratic or Systematic?

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To document the trace element evolution of granitic quartz we sampled 120 granitic pegmatite localities in South Norway. The granitic pegmatites comprise two major pegmatite fields that were thoroughly studied throughout the past decades in terms of their major and accessory mineralogy and stable and radiogenic isotopes. Therefore, we have a solid geological framework to study and interpret the petrogenesis of granitic quartz.

The two pegmatite fields share many similarities and are nearly indistinguishable in terms of their mineralogy, radiogenic isotope signature and, partially, in their accessory mineral assemblages. Accordingly, both pegmatite fields comprises REE-Nb-Ta type pegmatites with Rb/Sr-ages close to 850 Ma and have relatively low ⁸⁷Sr/⁸⁶Sr isotope ratios of only 0.7062-0.7064.

The trace and major element distribution in feldspars is indistinguishable and follows overlapping trends during igneous evolution of the granitic melts from typical K/Rb ratios in K-feldspar of 360 in the most primitive pegmatites to 100 at the most evolved localities.

However, a recent study of the REE distribution in K-feldspar (Larsen, 2002, The Canadian Mineralogist, 40, 137-151) unequivocally demonstrate that the parent melts forming the two pegmatite fields were derived from different source regions and that the REE mineral assemblage that buffered the REE-distribution in K-feldspar and the melts show subtle but distinctive differences.

Contrary to feldspar, the distributions of structurally bound trace elements in quartz (i.e. either substituting for Si or acting as charge compensators that are confined to lattice vacancies or open structural channels) confirm the incompatibility of the two pegmatite fields. Laser Ablation ICP-MS analysis of quartz show that the concentration of Li, Be, Al, P, Ti and Ge change systematically during igneous differentiation towards progressively more evolved pegmatites. Ti has a pronounced compatible geochemical behavior whereas Ge and Li are incompatible and obtain highest concentrations in the most evolved pegmatites. Particularly the Ge/Ti and the Ti/Li ratios of quartz efficiently trace the igneous evolution of the granitic melts. Moreover, when plotting these ratios against other trace elements in quartz the two pegmatite fields follows widely different evolutionary paths during igneous differentiation of the granitic melts. Sudden abrupt deviations from the igneous path are recorded at some localities and, although not fully resolved, may record the onset of H₂O saturation and nucleation of an aqueous phase. In conclusion, our studies demonstrate that structural bound trace elements in igneous quartz in deed follow systematic and predictable trends during AFC-processes in granitic magma chambers. Moreover, when compared to other common phases in the granitic mineral assemblage, quartz may be superior in distinguishing the origin and evolution of granitic rocks in regions that have experienced long and complex igneous histories.

V62A-1383 1330h POSTER

Trace Element Effects of Basalt Contamination by Phonolite: a Little Goes a Long Way.

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The Diego Hernandez Formation (hereafter DHF) from Tenerife (Canary Islands, Spain) is a complex eruptive sequence of alternating phonolitic tephros and basaltic lavas and scoria. Phonolitic eruptive centers were within a central caldera, whereas basaltic rocks in this study were predominantly erupted from outside the caldera. Basaltic rocks are basaltic/tephritic to alkali basaltic in composition, with phenocryst assemblages of olivine ± titanite ± magnetite (± rare plagioclase). The most primitive basaltic rocks show depletion in Rb, Ba, Th, U, K and Pb with respect to Nb, Ta and La, and no enrichment of Zr and Hf with respect to elements of similar incompatibility (Sm, Ti). Phonolite trace element compositions are very distinctive due the high degree of fractionation, with trace element signatures being strongly controlled by the fractionation of titanite. This has resulted in strong depletion of Ba, K, Sr, Ti, and MREE among phonolites, and consequently high Ba/Th, Zr/Sm, Pb/Ce, and Nb/Ta. This signature may be recognized in diluted form among several of the DHF basaltic units; among other consequences, this results in enrichment of U and Th relative to K and Ba, which could be interpreted as evidence for a residual potassic phase in the mantle source if the effects of contamination by phonolite are not taken into account. Petrographic evidence for contamination is found in some lavas: green-core pyroxene phenocrysts, occasional resorbed alkali feldspars, and rare resorbed sphene. There is no correlation between indices of phonolitic contamination and distance of basaltic vents from the caldera over 5 km distance, hence the contaminant may be accessible at depth over an area greater than that of the caldera.

The significance of the trace element variation, in conjunction with stratigraphy, is that the DH magma system shows genuine bimodality; periodically replenished basaltic magma may or may not come in contact with coexisting phonolitic magma during ascent. It is also feasible that phonolitic pumice, not magma, may be assimilated during ascent, giving rise to phonolitic magma-like contamination signatures. Regardless of the physical nature of the assimilate, we show that small amounts (ca. 5%) of felsic contamination have significant effects on basalt trace element concentrations and incompatible element ratios.

V62A-1384 1330h POSTER

Zircon Geochronology and Geochemistry of the Acasta Gneiss Complex in Slave Province, Northern Canada

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Ancient crustal rocks provide direct evidence for the processes and products of early Earth differentiation. The Acasta Gneisses have been established as the oldest known intact terrestrial rocks (Bowring et al., 1989). The Acasta Gneisses are exposed along the western margin of the Archaean Slave Province in the northwest corner of the Canadian Shield. The Acasta Gneiss Complex comprises mainly of Gray Gneiss (granodioritic gneiss), White Gneiss (tonalitic to granitic gneiss), and Foliated Granite, with many aplite and basaltic intrusions, and the relation between these rocks is very complex. In 2000 and 2002, we carried out geological mapping in detail with 1:5000 scales, and collected over 1,000 rock samples from the Complex in order to reveal the relation. In this study, extracted over 1,000 zircons were separated from rock samples, and were imaged using cathodoluminescence in order to ascertain the internal structure of the zircons. The type of structure divided into core, mantle, rim and recrystallization. And we analyzed U-Pb age and Rare Earth Element (REE) abundances from 20 micro meter spot using laser ablation inductively coupled plasma mass spectrometry.

The zircon grains from White Gneiss are mostly turbid, inclusion rich and heterogeneous. U-Pb ages for core region are scattered between 4.0Ga and 3.4Ga, while those for rim region are scattered between 3.75Ga

and 3.4Ga. And the analyses of Foliated Granite indicate an age of 3.6Ga. These results demonstrated that at least four magmatic or metamorphic events occurred in the Acasta Gneiss Complex; 4.0-3.95Ga, 3.75Ga, 3.6Ga and 3.4Ga. These results showed good agreement with those of previous studies (Bowring and Williams, 1995, Stern and Bleeker, 1997, Sano et al., 1999). Moreover, in this work we discovered a zircon from White Gneiss with a Pb/Pb age as old as 4,203 +/- 28Myr - about 150 million years older than any previously identified in the Acasta Gneiss Complex. This would seem to show that the White Gneiss rock incorporated a small amount of older material. On the other hand, the results of REE abundances for samples were complicated. This is mainly because most zircon grains contained many inclusions and cracks.

V62A-1385 1330h POSTER

The Bowen-Fenner Debate Revisited: A Review of Basalt Crystal Fractionation and the Generation of Andesite

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The Bowen-Fenner debate over the nature of basalt crystal fractionation is still unresolved. Bowen's classic 1928 book detailed his basalt-andesite-rhyolite fractionation scheme, whereas Fenner emphasized the evidence for Fe-enrichment during most basalt crystallization, thus anticipating discovery of the Skaergaard. In the 1940's Bowen suggested only wet basalt generates common andesite. To address this debate MELTS simulations were performed with near-constant parents but varied water contents from 0-4 wt per cent. For comparison, data were compiled from mid-ocean ridge (MORB), back-arc basin (BABB), and arc basalts. There is a strong correlation between empirical fractionation patterns and the simulations. Dry basaltic magma exemplified by MORB shows fractionation patterns controlled by early plagioclase crystallization, whereas nearly all wet arc basaltic magmas have patterns controlled by crystallization of mafic minerals, with the later onset of highly calcic plagioclase. BABB have fractionation patterns between those two extremes. The fundamental antithetic behavior of Al and Fe during basalt crystal fractionation due to the sensitive control over plagioclase crystallization by water is completely obscured by the use of Harker and AFM diagrams. Mafic arc basalts which show evidence for significant crystallization of magnetite are largely lacking - most arc basalt fractionation patterns are consistent with 2-3 per cent H₂O in the primitive melt and oxygen fugacity near the NNO buffer. A few mafic arc volcanoes have steep increases in Al content or slightly declining Fe content with only slight increases in FeO*/MgO suggestive of significant magnetite crystallization. Magma at these centers must be somewhat more hydrous and/or oxidized than is the normal case. Arc basalt clinopyroxene compositions support the inference that common high-alumina basalt (HAB) is a derivative magma, as empirical and experimental data, and MELTS simulations, all show coupled increases in Al and Fe/Mg in cpx, consistent with crystallization from increasingly aluminous wet magma.

Further plagioclase-dominated fractionation of HAB in arcs in most cases generates Fe-rich basalt or basaltic andesite, consistent with lack of significant magnetite in HAB and mafic Fe-rich HAB groundmass compositions. Differentiation of HAB (by AFC?) may include Al-rich tholeiitic andesite, but not typical calc-alkaline andesite. The latter is likely made by magma mixing, as suggested by ubiquitous mineralogic disequilibrium, low Al content, and P systematics. P behaves incompatibly in virtually all common, non-alkaline, mafic arc magma, and apatite crystallization does not commence soon enough in mafic arc magma to buffer P concentrations in common andesite. Typical basalt to andesite mass balance fractionation models ignore P and fail P mass balance.

V62A-1386 1330h POSTER

Rocks Whose Compositions are Determined by Flow Differentiation of Olivine- and Sulfide Droplet-Laden Magma: the Jinchuan Story

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The Jinchuan intrusion in western China is an elongated, deeply-dipping dyke-like body of dominantly olivine-rich ultramafic rocks of high magnesium basaltic magma. It hosts the second largest Ni-Cu sulfide deposit in the world. More than 500 million tonnes of sulfide ore grading 1.2 percent Ni and 0.7 percent Cu occur mostly as next-textured and disseminated sulfide (pyrrhotite, pentlandite and chalcopyrite) with cumulus olivine in about half of the rocks of the intrusion. Based on different petrological zonations, the Jinchuan intrusion is further divided into three segments: eastern, central and western segments. The central segment is characterized by concentric enrichments of cumulus olivine and sulfide, whereas the eastern and western segments are characterized by the increase of both cumulus olivine and sulfide toward the footwall. The forsterite contents of fresh olivine from different segments are similar and vary between 82 and 86 mole percent. The small range of olivine compositional variation corresponds to less than 6 percent of fractional crystallization. Mass balance calculations based on sulfide solubility in basaltic magma indicate that the volume of the parental magma of the sulfide is many times larger than that which is currently represented in the intrusion. Large amounts of cumulus olivine (more than 40 weight percent) in the marginal samples and high concentrations of sulfide in the intrusion are consistent with an interpretation that the Jinchuan intrusion was formed by olivine- and sulfide droplet-laden magma ascending through a subvertical conduit to a higher level. Differentiation processes of the olivine- and sulfide droplet-laden magma varied in different parts of the conduit. Sub-vertical flow differentiation controlled the central segment of the conduit, resulting in further enrichment of olivine crystals and sulfide droplets in the conduit center. In contrast, sub-lateral flow and gravitational differentiation dominated in the eastern and western segments, resulting in further enrichments of olivine crystals and sulfide droplets toward the footwall contact.

V62A-1387 1330h POSTER

Kinetics of melt-rock reaction in partially molten rocks with applications to harzburgite-dunite dissolutional transformation

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When an interstitial melt and its host crystalline matrix is out of chemical equilibrium, dissolution or/and precipitation takes place. The kinetics of melt-rock reaction in partially molten, solid solution forming silicates was examined in a combined experimental and numerical study. Two regimes of crystal-melt interaction were identified: diffusion-in-melt-limited dissolution (Regime I dissolution for short) and diffusion-in-solid-limited re-precipitation (Regime II). Because the rate of diffusion in the melt is much faster than rate of diffusion in the solid, Regime I dissolution is equivalent to complete disequilibrium dissolution. When extensive solid solution exists in the crystal the amount of solid dissolved during Regime I dissolution is always greater than that expected from the lever rule. The interstitial melt is in equilibrium with the surface of the dissolving crystal at the end of Regime I dissolution and Regime II dissolution commences. Compared to its surface composition the interior of the compositionally zoned crystal appears over-saturated with respect to the interstitial melt and hence dissolution reverses to re-precipitation that finally stops when the concentration gradient in the crystal is eliminated. The final equilibrium crystal and melt compositions and crystal-melt proportion are identical to the values predicted by the lever rule. Obviously it is the kinetics that determines how fast and along which concentration paths crystal and melt are en route to their final equilibrium compositions and proportion.

Our experimental study of the kinetics of melt-rock reaction is focused on harzburgite reactive dissolution. Dissolution of harzburgite in basaltic liquids (1250-1300°C and 0.5-1 GPa) produces a melt-bearing, orthopyroxene-free dunite. As a result of Regime I dissolution the orthopyroxene abundance drops abruptly to zero across the planar harzburgite-dunite interface. Developed around the harzburgite-dunite sharp interface (mostly on the dunite side) is a broad concentration boundary layer where major, minor, and trace element abundances in olivine vary systematically as a function of distance and dissolution time. The composition boundary layer is formed by Regime II re-precipitation. By treating the harzburgite-dunite dissolutional transformation as a moving boundary problem we found that the magnitudes of the concentrations and the signs of the concentration gradients in the composition boundary layer depend strongly on the compositions of the harzburgite and the through-going melt. Hence either positive or negative correlations between the Mg# of olivine and the NiO content in olivine can be expected as one crosses a harzburgite-dunite sharp interface. Several field studies have found systematic variations in mineral chemistry (e.g., Mg#, NiO, CaO in olivine and Mg# and Cr# in spinel) across

the dunite-harzburgite contact in the mantle sections of ophiolites. These systematic variations are broadly consistent with our numerical calculations and laboratory harzburgite reactive dissolution experiments. Results of our kinetic studies will be integrated into a mass transfer model that, once combined with field observations, can be used to estimate the through-going melt composition and the time-scale of melt extraction. It is in the vicinity of a harzburgite-dunite contact that one is most likely find evidence of melt-rock reaction.

V62A-1388 1330h POSTER

Evidence for Extremely Shallow-Level Assimilation of Phonolitic Pumice By Basaltic Magma, Diego Hernandez Formation, Tenerife, Canary Islands, Spain

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A 25 meter-wide basaltic dike crosscuts some 120 m of phonolitic pumice deposits in the Diego Hernandez Formation (DHF) in the Las Cañadas caldera complex on Tenerife. Direct field observation of fingers and lenses of basaltic magma irregularly radiating from the main dike indicates intrusion into unconsolidated pumice, while fragments and aggregates of pumice up to several cm in size have been mechanically incorporated by the basaltic magma. Entrained phonolitic pumice fragments, originally glassy, are now crystalline and resemble microsyenites. The basalt includes numerous re-sorbed feldspar, pyroxene, and biotite phenocrysts inherited from melted pumice. Major and trace element data constrain some of the entrained pumices to have originated from layers in the DHF section that occur no more than 80 m below where they are found, and 100 m below the paleosurface onto which the dike erupted. These observations show that shallow mafic magmas on Tenerife, within a few hundred meters of the surface, are capable of assimilating phonolitic pumices. Geochemical data from mafic lavas within the DHF section show that contamination by phonolite has been an important process in their petrogenesis, but do not allow identification of the physical nature of the phonolitic composition contaminant. The evidence from the dike is that at least some of this contamination may have occurred very near the surface. Assimilation of pumice in a near surface environment, where thermal barriers would seem formidable, is facilitated by its glassy nature. This may be an important, overlooked process in central volcanoes where mafic magmas erupt through thick felsic pyroclastic formations.

V62A-1389 1330h POSTER

An Interior View of the Springerville Volcanic Field, AZ Magma Plumbing System

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The Springerville Volcanic Field (SVF) is one of the larger predominantly basaltic fields in the coterminous U.S. Positioned at the margin of the Colorado Plateau, the SVF is ideally situated for examining the interplay of tectonic processes and basaltic magmatism. To better understand the nature of magma conduit development, we have applied crystallization barometers and thermometers to determine the depths and temperatures at which magmas pond and partially crystallize. Such calculations are crucial for comparing magma staging depths to crustal structure, and thus for elucidating the physical controls on magma transport. Crystallization depths are calculated from clinopyroxene-liquid pairs using experimentally calibrated thermobarometers.

SVF liquids are represented by whole rocks where clinopyroxene saturation models (Putirka, 1999) suggest an approach to equilibrium between whole rock and clinopyroxene phenocryst compositions. These calculations show that while crystallization occurs at a wide range of depths beneath the SVF, crystallization depths largely cluster within two distinct levels

within the crust, centered at 5 and 27 km. Crystallization depths, and depth-density relationships, contradict the view that magmas pond at the Moho. Instead, magmas appear to stall at a rheologic contrast at the middle/lower crust boundary (27 km), and at a shallow-level density contrast within the upper crust (5 km). Moreover, crystallization depths overlap with seismically reflective mid-crustal layers identified for the Colorado Plateau and Transition Zone, providing compelling support for existing models (Parsons et al., 1992) in which seismically reflective layers represent magmatic sills related to recent volcanic activity. Finally, elevated values of K, K/Ti, and Si occur only for samples that partially crystallized within one of the two prominent stagnation depths noted above; such relationships suggest that these magmatic sills represent primary sites of liquid evolution. Thus, while partial crystallization may occur over a broad range of depths, substantial liquid evolution in the SVF appears to require some residence time within a magma chamber or sill.

V62A-1390 1330h POSTER

Open-System Alkaline Magmatism in the Caledonides of North-Central Norway

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The Caledonian-age Hortavaer intrusion is exposed on small islands and skerries off the coast of north-central Norway. It was emplaced into a range of host rocks that includes calcitic and dolomitic marble to migmatitic gneiss to quartz-rich meta-arenite. The intrusion is unusual relative to Caledonian plutons on the mainland because of its alkaline nature and its possible circa 460-470 Ma age (based on imprecise Sr and Nd isochrones). The intrusion is broadly zoned, with central diorite and outer syenite. Dike-like bodies of monzonite and syenite are also present and are elongate in a NNE-SSW direction.

Each lithologic unit is characterized by evidence for magma mingling, particularly by synplutonic dikes and enclaves. In the syenitic zone, mingled magmas ranged from monzonitic (syenitic) to dioritic. In the diorite zone, mingling was dominated by diorite-in-diorite, but composite diorite-syenite dikes are present. The contact between the syenite and diorite units is marked by an approximately 500-m-wide zone of sheeted diorite/syenite dikes that are mutually intrusive. In addition to magma mingling, the complex shows a variety of types of interaction with screens of its host rocks, which are typically subparallel to foliation in the pluton. Some screens were apparently unreactive with the surrounding magma, whereas others resulted in intense reaction and formation of garnet melasyenite, pyroxene-rich monzodiorite, and rare nepheline-bearing rocks.

A trend toward Fe enrichment among the dioritic rocks, the low Mg/(Mg+Fe) and Sr contents of the evolved syenites, and curvilinear composition trends for many elements in the suite suggest fractional crystallization was a major control on magma evolution. However, low epsilon Nd (465 Ma) (-3 to -10), moderate initial 87Sr/86Sr (0.705 to 0.710), and high delta18O (+8.3 to +14.0) suggest either a crustal source or intense contamination. The presence of primary calcite with delta13C typical of host carbonate rocks suggests that assimilation was important in the pluton, and was perhaps promoted by evolution of mixed CO2-H2O fluid during assimilation of carbonate rich metasedimentary rocks.

V62A-1391 1330h POSTER

Disequilibrium Crustal Anatexis During the Formation of Migmatite in the Southern Sierra Nevada Batholith, California

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We provide data on the geochemical and isotopic consequences of non-modal partial melting of a thick Jurassic pelite unit at mid-crustal levels that was induced by the intrusion of the Goat Ranch granodiorite at 100Ma. Field relations suggest that this pelitic migmatite formed and then abruptly solidified prior to substantial mobilization and escape of its melt products. Hence this area yields insights into potential mid-crustal level contributions of crustal components

into Cordilleran-type batholiths. Major and trace element analysis in addition to field and petrographic data demonstrate that leucosomes are products from partial melting of the pelitic protolith. Compared with the metapelites, leucosomes have higher Sr, lower Nd and Sm concentrations and lower Rb/Sr ratios. The initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of leucosomes range from 0.7125 to 0.7246, and are similar to those of the metapelite protoliths (0.7125 to 0.7243). However, the leucosomes have a much wider range of initial ϵ_{Nd} which range from -5.5 to -12.0, as compared to -8.5 to -12.3 for the metapelites. Sr and Nd isotope compositions of leucosomes, mesosomes, migmatites and metapelites suggest a disequilibrium partial melting of the metapelite protolith. In a spider diagram, two leucosomes show distinct positive Eu anomalies while the other two have negative Eu anomalies, and metapelites show consistent negative Eu anomalies. Leucosomes with negative Eu anomalies have lower Rb concentrations than metapelites and other leucosomes with positive Eu anomalies. The lower Rb concentrations and Rb/Sr ratios of these leucosomes together suggest that partial melting of metapelite is non-modal and dominated by biotite dehydration. However, the other leucosomes have greater contributions from K-feldspar breakdown, which is consistent with their relative high K concentrations and positive Eu anomalies. The various degrees of parent/daughter fractionation of both the Rb-Sr and Sm-Nd systems as a consequence of non-modal crustal anatexis would render distinct isotopic reservoirs that could profoundly influence the products of subsequent mixing events. This is not only critical for intracrustal differentiation, but also potentially an important process in generating crustal isotopic heterogeneities.

V62A-1392 1330h POSTER

Igneous Petrology of the Rift to Drift Transition in Central East Greenland

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Fifteen-hundred meters of early Paleogene tholeiites of the Milne Land Formation (MLF) in central east Greenland mark the onset of flood basalt volcanism associated with continental break-up in the North Atlantic. This stratigraphy links the compositionally diverse lower volcanics (rift succession) to the more homogenous lavas of the Geikie Plateau Formation (early drift succession) with no evidence for a hiatus in volcanism, as previously suggested. Volumetrically, the MLF is dominated by evolved FeTi basalt showing systematic variation in rare earth element (REE) abundances with stratigraphic height indicative of a decline in the mean extent and pressure of partial melting with time (Tegner et al., 1998, *Nature*, 395). In addition, three petrographically and geochemically distinct lava suites occur in the MLF: picrite-ankaramite, orthopyroxene (opx) phryic ankaramite, and low-TiO₂ basalt. Picrite and ankaramite flows occur exclusively in the lower 200m of the formation and are up to 35m thick. They have near-chondritic La/Sm ratios, Dy/Yb_N ratios of 1.4-1.8, and Zr/Nb ratios of 14-17, similar to primitive basalts of the lower volcanics (Fram and Leshner, 1997, *J. Petrol.*, 38). Coarse-grained opx phryic ankaramite flows are ~10m thick with basal zones of crystal accumulation containing resorbed olivine (Fo₈₀₋₈₃), and subhedral clinopyroxene (Wo₃₁₋₃₈, En₄₄₋₅₆, Fs₇₋₂₄) and opx (Wo₅₋₉, En₆₂₋₇₇, Fs₁₈₋₃₀) phenocrysts. These lavas have Dy/Yb_N and Zr/Nb ratios similar to the picrite-ankaramite suite, but markedly higher La/Sm_N ratios (> 1.5). They occur ~400m above the base of MLF with lavas lacking opx but having high SiO₂ (>52wt%) or Ba/Ti × 1000 > 20. These latter characteristics indicate crustal contamination of fractionated magmas, while the opx ankaramites reflect contamination of more primitive melts at lower crustal conditions. The low-Ti suite has sub-chondritic La/Sm ratios, near-chondritic Dy/Yb ratios, and Zr/Nb ratios of 20-55. These aphyric to sparsely phryic flows are restricted to the upper 500m of the MLF and are <10m thick. The appearance of these depleted basalts marks the onset of ocean floor-type spreading in the region, while eruption of more enriched primitive and contaminated magmas reflect the establishment of more direct conduits through the continental lithosphere accompanying plate separation. Trace element systematics among the dominant FeTi basalts, picrite-ankaramite, and low-Ti suites can be related through variable extents of melting of a heterogeneous mantle source that may contain components of subducted Iapetus crust.

V62A-1393 1330h POSTER

Origin of Large Felsic Rock Volumes in Marie Byrd Land Volcanoes: Possible Influence of Tectonic Environment and Continental Lithospheric Structure

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The Marie Byrd Land volcanic province, in the West Antarctic rift system, includes several volcanoes with large volumes of peralkaline trachyte, phonolite, and rhyolite. The roughly 780 cu. km. of trachyte at Mt. Takahe volcano, for example, is about twice the volume of Mt. Shasta, the largest Cascade volcano. Geochemical data provide evidence for only minor amounts of crustal contamination, affecting just a small proportion of the felsic rocks, hence crustal assimilation is unlikely to have supplemented the volume of felsic rocks. Most appear to have been derived entirely by fractional crystallization of basaltic magma; but the volumes of felsic rock in Marie Byrd Land volcanoes is much larger than is found in their counterparts in oceanic islands, produced by essentially the same process, suggesting that continental structure and/or tectonic environment may have played a role in felsic rock evolution. The absence of Antarctic plate motion, over at least the past 26 m.y., seems an obvious factor. This has apparently led to repeated replenishment of the same magma chambers, rather than formation of linear chains of volcanoes. In addition, modeling results suggest that a multi-level, polybaric plumbing system within the lithosphere has acted as a filter, delaying the rise of at least some large volume magma batches, thereby prolonging and refining the fractionation process.

V62B MCC: Hall C Saturday 1330h

Xenoliths, Mafic+Felsic Magmatism Posters

Presiding: S B Mukasa, University of Michigan

V62B-1394 1330h POSTER

The Askja- Sveinagja Connection: Implications for the Origin of Low O-18 Magmas in Iceland

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In our on-going effort to better understand the origin of low O-18 magmas in Iceland we have obtained new oxygen isotopic data for whole rocks from the Askja and Sveinagja volcanoes, NE-Iceland. We hoped to test the relationship between Askja and Sveinagja, namely the idea that the Sveinagja 1875 fissure eruption was fed by magma migration from a shallow magma chamber located under Askja (50-70 km to the south).

Basalts were sampled from Askja (16) and Sveinagja (10). Several Askja samples came from inside the caldera but most were collected from a lava fan on the western side of the volcano. This sample set covers a time span from the end of the ice age up to the 1961 Askja eruption. Sveinagja samples are from the fissure eruption of 1875 and were taken from the southern- and northernmost edges of the flow.

The overall range in delta O-18 values is from +3.2 to +4.1‰ (wrt V-SMOW). Askja covers the entire range but Sveinagja is less variable (+3.7 to +4.1‰). Chemically, Askja and Sveinagja lavas are similar both in terms of major and trace element concentrations. MgO (wt%) for the lavas varies from 7.5 to 4.5 with Sveinagja towards the evolved end. Modeling shows that the most evolved basalts in the series can be obtained through 47% crystal fractionation. Crystal fractionation, however, had minimal effect on the delta O-18 values.

Comparison with more evolved Askja products is revealing. The Askja 1875 rhyolite delta O-18 values cluster around 0‰ and the MgO is 0.2 wt%. Acidic xenoliths (MgO near 0 wt%) have even lower delta O-18 values ranging down to -10‰.

It is clearly impossible to generate the 1875 rhyolite by simple mixing between magmas represented by

the mafic lavas and the acidic xenoliths. Moreover, the Askja basalts appear to have experienced little crustal interaction during their ascent to the surface. The chemical and isotopic similarities between the Askja and Sveinagja basalts suggest evolution in a common magma reservoir possibly at 10-15 km depth. This implies that low O-18 magmas may exist beneath Iceland at even deeper crustal levels.

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Oxygen Isotopic Ratios of Mafic Volcanics from the Langjokull Region, Iceland

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The Langjokull region is located at an interesting juncture within the Icelandic volcanic belts. It sits at the northern end of the Western Volcanic Zone (WVZ), and is flanked by the off-rift Snaefellsnes Volcanic Zone (SVZ) to the west, and by the Mid-Iceland Belt to the east (MIB). The WVZ and MIB have produced low O-18 basaltic magmas (4.0-5.5‰), whereas the SVZ has produced magmas with MORB-like values (5.5-6.0‰).

During the Upper-Pleistocene (0.01-0.78 Ma) the Langjokull region was covered with 0.75-0.85 km thick glacier. Subglacial eruptions produced two morphologically distinct types of volcanoes: ridges and tuyas. In either case these eruptions generated a distinct lithofacies sequence. The earliest eruptive phase formed basal pillow lava. This was followed by hyaloclastite, and then finally, when the volcano broke the ice, subaerial lava. Dikes were intruded through the hyaloclastite during the last stages of the eruptions.

We have obtained delta O-18 values for 21 basalts from six different ridges and tuyas in the region. These samples include every the lithofacies type except hyaloclastite. Two to five samples were taken from each volcano most from the tuyas.

Delta O-18 values for the whole rock suite range from 4.0-5.5‰ (wrt V-SMOW). However, variations within each volcano are less than 0.5‰. There is no clear correlation between major element chemistry and delta O-18 values indicating that fractionation had little effect. MgO values for these rocks vary from 6-13 wt%. There is a slight hint of regional variation in our data. Thus the northernmost tuya (Eiriksajokull) has the highest delta O-18 values, whereas the southernmost tuya (Hlodufell) has the lowest.

It is interesting to note that even the largest of these volcanoes, the 48 km³ tuya Eiriksajokull, shows little variation in delta O-18 (5.0-5.4‰). This is in stark contrast with the chemically similar but younger, smaller (15 km³) shield volcano to the south. The delta O-18 values of the shield volcano (Skjaldbreiður) vary between 4.6 and 5.5‰. It thus appears that, in terms of O-18, more homogeneous melts were produced in the Langjokull region than during recent times.

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Trace Element Geochemistry of Alkalic Rocks from Haleakala Volcano, Hawaii

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Field and chemical studies of volcanic rocks in Hawaii have revealed that the islands were formed through four distinct stages of volcanism: pre-shield, shield, post-shield, and post-erosional (Clague and Dalrymple, 1987). The alkalic rocks produced during the post-erosional stage of island development are believed to be the result of either low-pressure fractionation of magmas or low degrees of melting of mantle source material.

Nine samples from Haleakala Volcano, East Maui, Hawaii ranging in composition from basalt to hawaiite to mugearite have been analyzed using INAA in order to estimate the degree of melting of source rocks required to produce the post-erosional stage alkalic rocks of the island. Five of these samples are from the post-erosional Hana Volcanic Series (HVS) and four are from the highly-alkalic historic flow (1790?).

A chondrite-normalized REE plot of the INAA data shows enrichment in light REE similar to plots for the alkalic Honolulu volcanics (Clague and Frey, 1982). Yb values for the Haleakala rocks range from 39 to 61 parts per million, indicating that garnet was not present in the zone of magma generation from mantle peridotite.

P-T calculations by Craven and Kilinc (2002) on the same series of post-erosional stage Hana Volcanic Series (HVS) and historic flow (1790?) samples indicate that they formed from 1417C/ 21.7 Kb to 1415C/